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INTRODUCTION

Status and progress in coral reef disease research

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ABSTRACT: Recent findings on the ecology, etiology and pathology of coral pathogens, host resistance mechanisms, previously unknown disease/syndromes and the global nature of coral reef diseases have increased our concern about the health and future of coral reef communities. Much of what has been discovered in the past 4 years is presented in this special issue. Among the significant findings, the role that various *Vibrio* species play in coral disease and health, the composition of the 'normal microbiota' of corals, and the possible role of viruses in the disease process are important additions to our knowledge. New information concerning disease resistance and vectors, variation in pathogen composition for both fungal diseases of gorgonians and black band disease across oceans, environmental effects on disease susceptibility and resistance, and temporal and spatial disease variations among different coral species is presented in a number of papers. While the Caribbean may still be the 'disease hot spot' for coral reefs, it is now clear that diseases of coral reef organisms have become a global threat to coral reefs and a major cause of reef deterioration.

KEY WORDS: Coral reef · Disease · Caribbean · Global threat · Reef deterioration · *Vibrio* · Disease resistance · Disease vectors

Over the past decades, coral reefs around the world have experienced significant changes in structure and function due to many interacting factors (Harvell et al. 1999, 2004, Hayes et al. 2001, Jackson et al. 2001, Wilkinson 2002, 2004, Gardner et al. 2003, Hughes et al. 2003, Pandolfi et al. 2003). Although the role or importance of each factor, or a combination of various factors, might vary across localities and/or regions, and time, diseases of coral reef organisms are becoming increasingly important in the deterioration dynamics of these important tropical marine communities. The Caribbean has been dubbed a 'disease hot spot' due to the fast emergence and high virulence of coral reef diseases/syndromes, their widespread geographic distribution, wide host ranges, and frequent epizootic events with significant coral mortalities (Epstein et al. 1998, Hayes & Goreau 1998, Green & Bruckner 2000, Weil et al. 2002a, Weil 2004). Currently, diseases of coral reef organisms have become the most important factor in the decline of coral reefs throughout the region (Weil 2004). In contrast, relatively few coral diseases and/or epizootic events have been reported for the Indo-Pacific, and these have generally been of both low prevalence and limited geographic distribution (Green & Bruckner 2000, Willis et al. 2004). However, as can be read throughout this issue and in the recently published book *Coral Health and Disease* (Rosenberg & Loya 2004), the number and distribution of coral diseases across the Indo-Pacific is also increasing.

Bleaching events have become more frequent and intensive, usually over wide geographic scales. In the Caribbean, bleaching has caused variable, but generally low coral mortality and nothing like the mass mortalities of the scale observed in the Indo-Pacific. Even the recent extensive bleaching of 2005, probably the worst ever recorded for the Caribbean (Fig. 1), has produced only limited, localized mortalities, some of which are the result of synergistic effects with other

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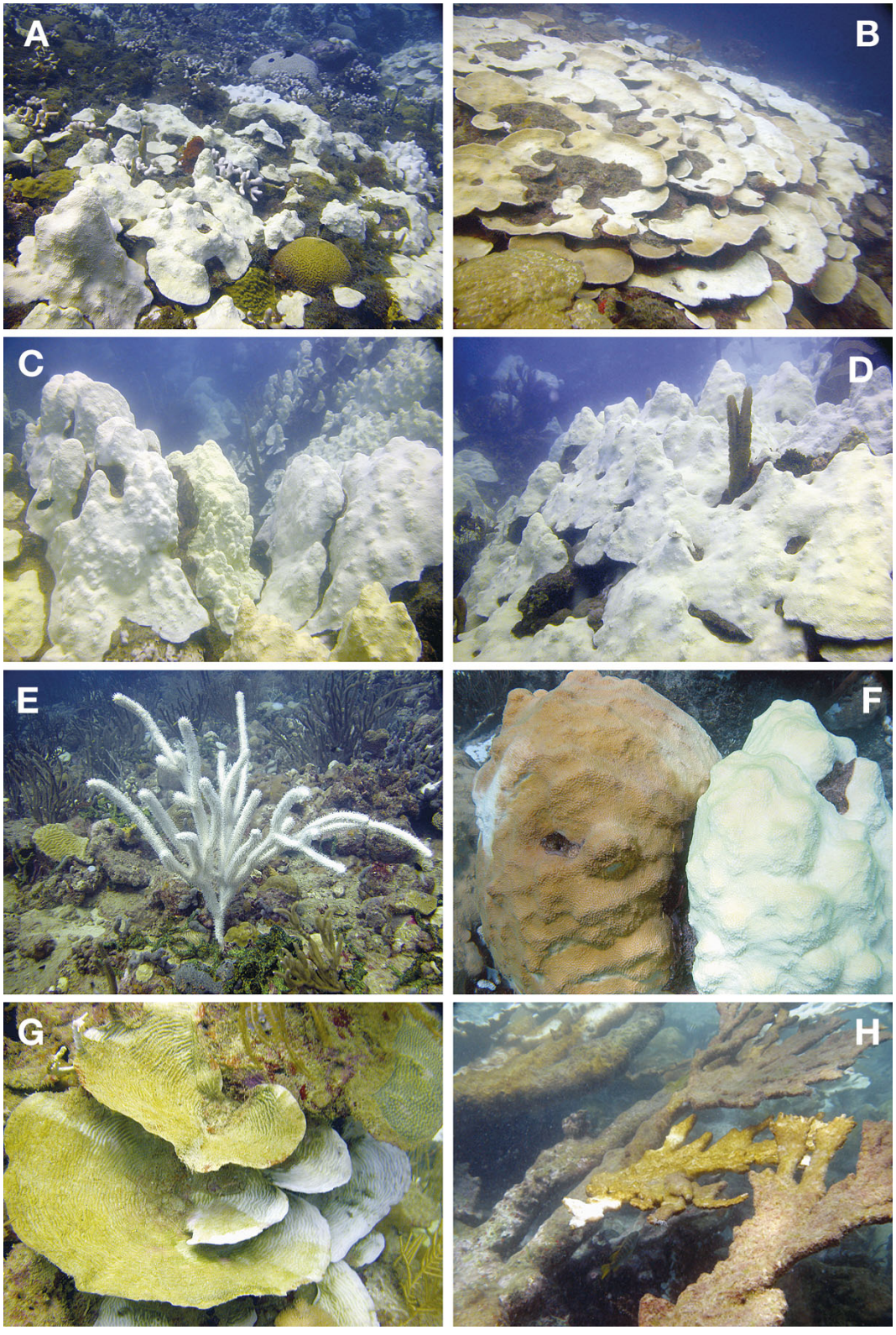

Fig. 1. Bleached reef communities in Grenada (A,B) and Puerto Rico (C,D) in 2005. A high proportion of octocorals (E), hydrocorals and zoanthids also bleached in many localities. Two side by side colonies of *Montastraea faveolata*, one bleached and the other not (F), pose interesting questions about the variability in response to temperature stress. Significant bleaching mortality was observed this time in *Undaria* (agaricids) (G), *Acropora* (H) and the hydrocoral *Millepora* in Puerto Rico

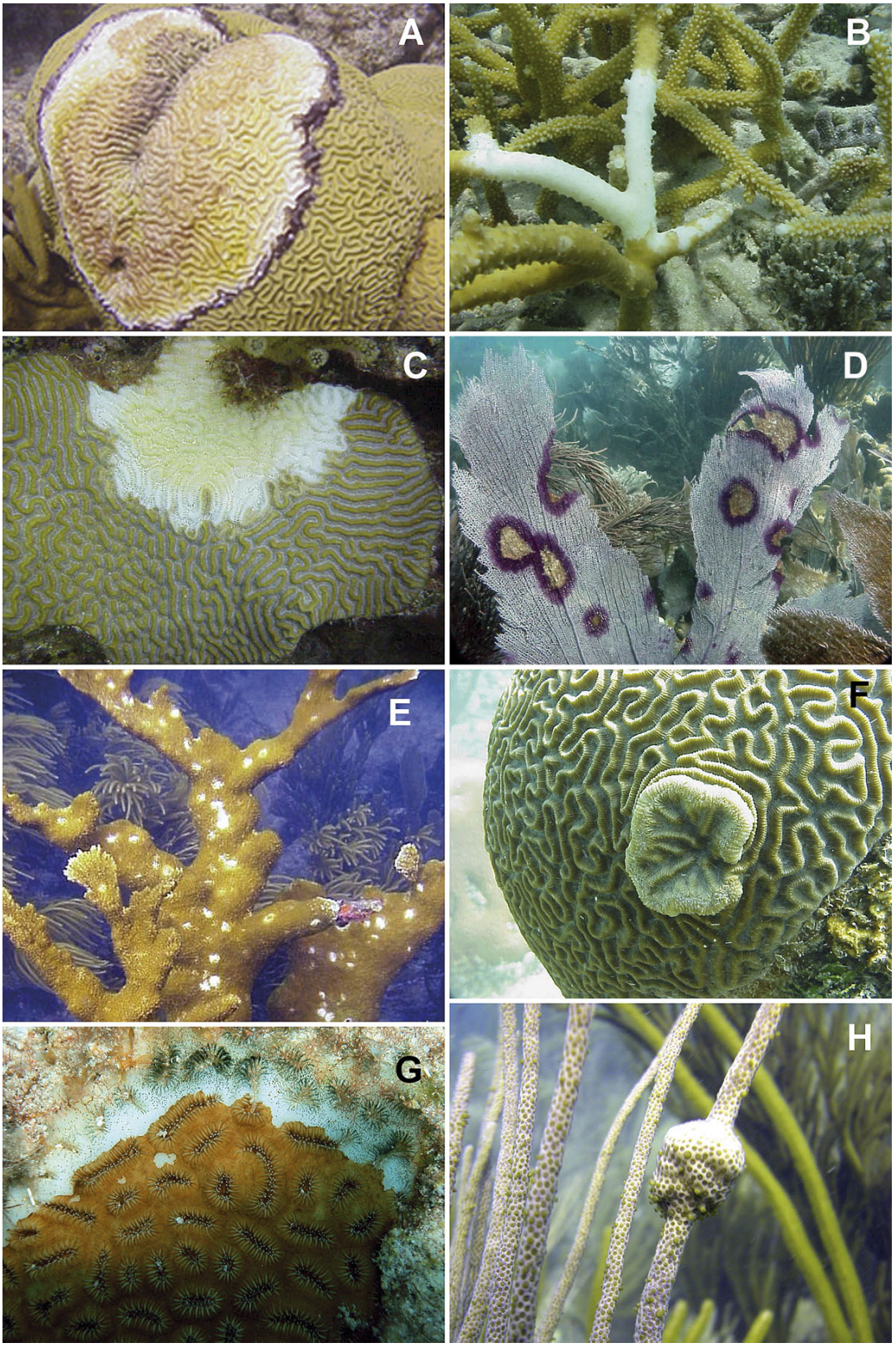

Fig. 2. Common diseases (pathogens known) in the Caribbean include black band disease (A), white band disease (B), white plague (C), aspergillosis (D), white pox (E), and tumors (F,H) in corals and octocorals. Secondary/opportunistic infection by a new ciliate (*Halofoliculina* sp.) is increasing in prevalence (G)

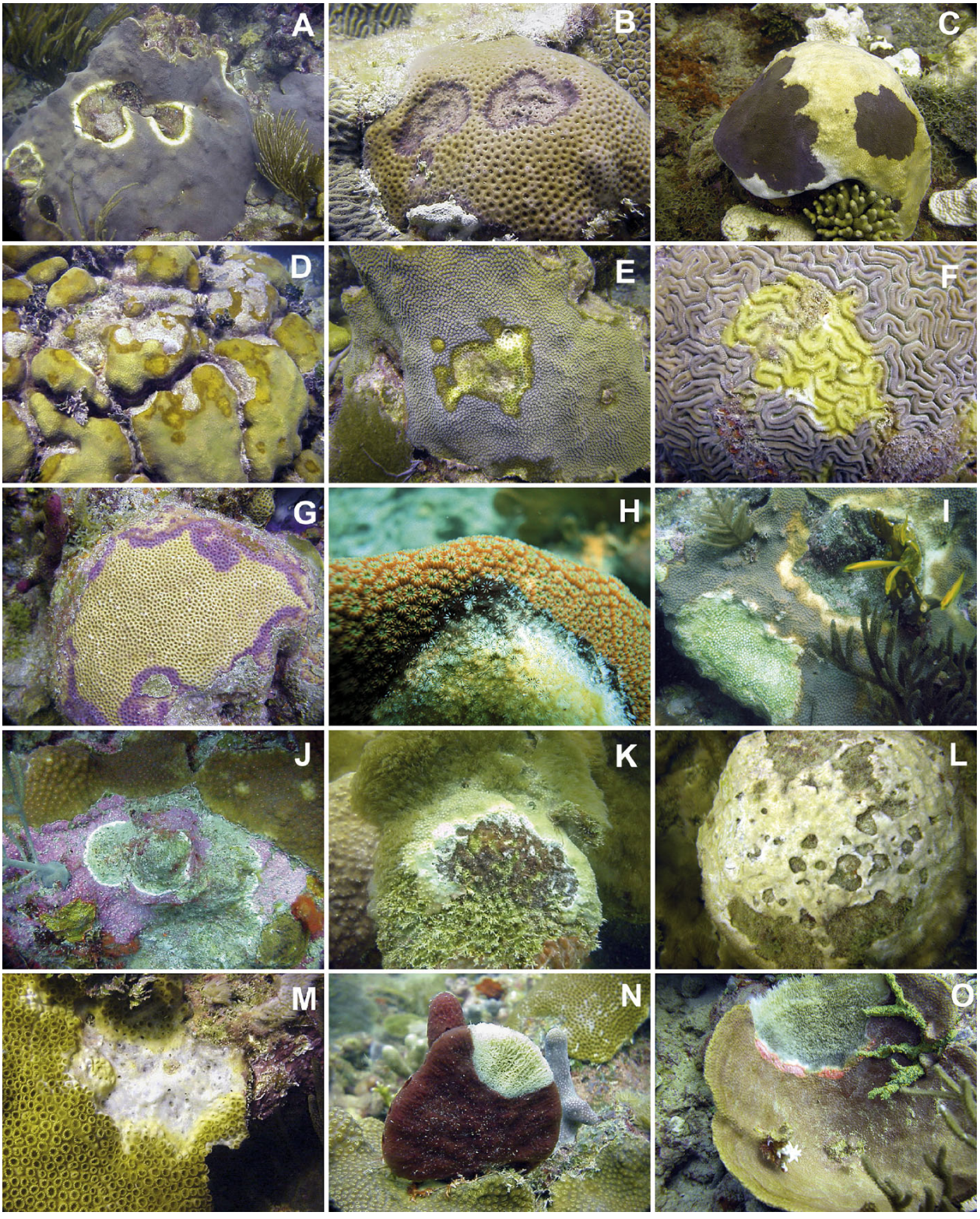

Fig. 3. Several syndromes (pathogens unknown) are affecting the common corals, some with devastating consequences, such as yellow blotch (A). Others are less virulent, like dark spots (B,C) and dark bands (D), while others like tissue necrosis (E,F,G) and the new ciliate (H) are still locally restricted. Increasing prevalence of colonies with multiple diseases (I) and syndromes affecting other important reefs organisms, such as crustose coralline algae (J), encrusting octocorals (K,L), zoanthids (M) and common sponges (N,O), is compounding the problem in the Caribbean

factors. The year 2005 was the first time in Puerto Rico that significant numbers of bleached reef organisms other than corals (Fig. 1) and high mortalities of common corals and hydrocorals were observed (Fig. 1G,H). The question remains, however, as to how the increase in frequency and intensity of these events would affect the emergence, dispersion and virulence of coral diseases. The potential of disease outbreaks to significantly change coral reefs was shown in the early 1980s by the disease-induced massive mortalities of 3 Caribbean keystone species, the black sea urchin *Diadema antillarum* (Lessios et al. 1984, Carpenter 1990a,b) and the acroporid corals *Acropora palmata* and *A. cervicornis* (Gladfelter 1982) over the wider Caribbean. These mortalities brought about a cascade of significant ecological changes in the dynamics, function and structure of coral reefs at local and geographic scales (Hughes 1994, Harvell et al. 1999, Aronson & Precht 2001, Bruckner et al. 2002, Lirman et al. 2002, Weil et al. 2002b, Weil 2004). Only one other widespread epizootic affecting the sea fan *Gorgonia ventalina* (Smith et al. 1996, Nagelkerken et al. 1997a,b, Kim et al. 2000, Harvell et al. 2002, Weil et al. 2002a, Smith & Weil 2004) has been reported for this region in recent times. In contrast, no widespread epizootics (other than bleaching) have been reported for the Indo-Pacific. Intensive and short-lived epizootics of the most common and aggressive diseases and syndromes (i.e. white plague, white band, patchy necrosis, and yellow band) are reported every year from several localities throughout the Caribbean, and recently, from the Indo-Pacific (Miller et al. 2002, Willis et al. 2004). More recently, ciliate (*Halofoliculina* sp.) infections (secondary/opportunistic parasites) have also been observed in the south and western Caribbean (Fig. 2).

Although causative agents for some of the most common diseases in the Caribbean have yet to be identified, primary pathogens for some of the most common diseases (Fig. 2) are now known. White plague in Florida was shown to be caused by a newly described genus *Aurantimonas* (Denner et al. 2003). *Serratia marcescens* was associated with white pox (Patterson et al. 2002) and a host of members of the genus *Vibrio* have been associated with a variety of coral diseases including bacterial bleaching (Kushmaro et al. 1996), white band disease (Ritchie & Smith 1998) and yellow blotch syndrome (Cervino et al. 2004) (Table 1).

Other important reef organisms such as sponges, zoanthids, octocorals and crustose algae have started to show disease signs and frequent disease outbreaks (Weil 2004, Ballantine et al. 2005) (Fig. 3J). Reports of pathogens affecting reef-building coralline red algae, another important reef-building group, were until recently only known from the tropical Pacific Ocean. Littler & Littler (1994, 1995, 1998) reported the presence of 2 disease conditions, coralline lethal orange

Table 1. Most common reported diseases (D) and syndromes (S) of Caribbean sessile coral reef organisms (scleractinian corals [COR], octocoral [OCT], sponges [SPO], crustose coralline algae [CCA] and zoanthids [ZOA]), their acronym, identified pathogen(s), and number of taxa affected. Updated from Weil (2004) and information from the authors' research

Disease (D) / syndrome (S)	Acronym	Pathogen	Number of species				
			COR	OCT	SPO	CCA	ZOA
Black band (D)	BBD	*Phormidium coralyticum*, *Desulfovibrio*, *Beggiatoa* sp.	19	6	–	–	–
White band-I	WBD-I	Gram (–) bacterium	2	–	–	–	–
White band-II (D)[a]	WBD-II	*Vibrio harveyi/charchariae*	2	–	–	–	–
White plague-I	WP-I	Gram (–) bacterium	12	–	–	–	–
White plague-II (D)[a]	WP-II	*Aurantimonas coralicida*	41	–	–	–	–
Aspergillosis (D)[a]	ASP	*Aspergillus sidowii*	–	10	–	–	–
White pox (D)[a]	WPX	*Serratia marsences*	1	–	–	–	–
Tumors (D)[b]	TUM	*Entocladia endozoica* (algae) and other causes	7	5	–	–	–
Red band (D)	RBD	*Oscillatoria* sp. and other cianobacteria	13	1	–	–	–
Neoplasia (S)	NEP	?	4	5	–	–	–
Shut down reaction	SDR	?	6	–	–	–	–
Yellow blotch (S)	YBS[d]	*Vibrio* spp.	11	–	–	–	–
Dark spots-I (S)	DSS-I[d]	?	10	–	–	–	–
Dark bands (S)	DBS-II[d]	?	8	–	–	–	–
Patchy necrosis (S)[c]	PNE[d]	?	1	–	–	–	–
Ring syndrome (S)	RIS	?	1	–	–	–	–
Tissue necrosis (S)	TNE	?	5	8	–	–	–
Octocoral tissue necrosis	OTN[d]	?	–	2	–	–	–
Sponge tissue necrosis	STN[d]	?	–	–	7	–	–
CCA white band (S)	CWB[d]	?	–	–	–	2	–
Zoanthid white band (S)	ZWB	?	–	–	–	–	1

[a]Koch's postulates fulfilled; [b]include hyperplasias and algal tumors; [c]patchy necrosis and white pox are considered the same by some researchers; [d]samples currently under investigation to identify putative pathogens

disease (CLOD), and an undescribed fungal pathogen on the coralline alga *Porolithon onkoides* in the Indo-Pacific. A white band-like syndrome has been found affecting a high proportion of colonies of at least 1 common crustose coralline red algae, *Neogonolithon accretum*, in many Caribbean localities (Weil 2004, Ballantine et al. 2005) (Fig. 3). Still, many syndromes have yet to be characterized and their putative pathogens identified (e.g. yellow blotch, dark spots, dark bands and tissue necrosis). As researchers become more familiar with disease signs and more pathological studies are carried out, the number of described diseases affecting corals and other organisms will increase. Even though many diseases and syndromes from the Indo-Pacific show similar signs to their Caribbean counterparts, pathological studies are showing interesting results. There has been no confirmation of common pathogens (with the exception of black band).

Contrary to what was expected for new emergent pathogens, host ranges for some diseases have been increasing with time. For example, white plague and aspergillosis have been reported to infect 41 coral and at least 6 octocoral species respectively (Smith & Weil 2004, Weil 2004) (Table 1). More recent observations indicate that an increasing number of colonies and species are being infected by more than just 1 disease/syndrome, there sometimes being as many as 4 (E. Weil & A. Croquer unpubl. data) (Fig. 3I).

Both the number and depth of study of microorganisms associated with corals has increased significantly. The 13 manuscripts presented in this special issue present the most recent advances and results in the study and experimentation with diseases of coral reef organisms throughout the world. We are pleased that our knowledge on this important topic is increasing fast through quality research.

Overall, papers in this special issue can be grouped into 4 general categories: (1) Regional assessments of diseases (Kaczmarsky 2006, for the Philippines; Ward et al. 2006, for the western Caribbean; Voss & Richardson 2006, for the eastern Caribbean and Page & Willis 2006, for the southwestern Pacific). (2) Prevalence and host interactions of specific diseases (Gochfeld et al. 2006, for dark spots disease; Bruckner & Bruckner 2006, for yellow band disease and Cróquer et al. 2006, for a ciliate disease). (3) Microbial communities (Pantos & Bythell 2006, for bacteria from white band disease; Gil-Agudelo et al. 2006, for metabolic changes with aspergillosis, Kim et al. 2006, for aspergillosis in sea fan corals and Davy et al. 2006, for viral associations). (4) Specific bacteria associated with specific diseases (Sussman et al. 2006, for black band/red band disease and Viehman et al. 2006, for black band disease). Significant advances in the microbiology of coral diseases are, therefore, presented in this volume. This, together with more information on the ecology and dynamics of the most virulent diseases, is providing much needed information which will enable researchers to start developing epidemiological models.

As human intervention in the environment increases, important questions such as how this will affect the emergence and prevalence of coral reef diseases, how we are to manage this problem at the population and community levels and what the consequences of this problem will be, still remain unanswered.

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